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Evaluation of Natural Ventilation Characteristics on the Sultanate of Ternate Mosque

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Abstract. Thermal comfort is very important in mosque buildings, especially during prayer times in order to increase the comfort and solemn in prayer. The usage of air conditioning for the mosque in Ternate City is not recommended because of the energy resources is limited (rotating blackout) and also to reduce its operational cost every month. Therefore, the application of natural ventilation is essential to improve thermal comfort in the mosque**.** This study aims to identify the characteristics of the natural ventilation system of Sultan Ternate Mosque by analyzing the orientation of inlet and outlet, ratio and dimension of openings, type and position of ventilation through the literature studies and field observations. The results show that the natural ventilation system of Sultan Ternate Mosque uses clerestory ventilation and cross ventilation systems, therefore the indoor thermal conditions can reach a comfortable level. Ventilation types are semicircular and vertical jalousie on the walls, and roof ventilation of 4-levels. The total area of ventilation holes are 110.24 m^2, with the ratio is about 1.04 (inlet): 1.00 (outlet).

Keywords: Sultan Ternate Mosque, Natural Ventilation, Cross Ventilation, Thermal Comfort

I. Introduction

Ventilation is a system in which the internal air is continuously replaced from an occupied space by the relatively fresh outside air through vents, windows, doors, and so forth. Three types of ventilation system are available such as forced ventilation, natural ventilation, and hybrid ventilation to improve the indoor air quality. Forced ventilation is served by powering a mechanical system such as fans, blowers, and so forth to push the external air into the space of interest. It is needless to note that this ventilation system consumes electric power in operation. On the other hand, the natural ventilation system neither consumes electric power nor needs any mechanical system [1]**.**

In buildings, electric power is mostly consumed by heating, ventilation, and air-conditioning (HVAC) systems. According to Awbi that ventilation consumes 30–60% of the total energy consumption in modern and retrofit buildings. The fossil fuel and nuclear power based electricity generations are discouraged by modern science and the fact due to global warming, environmental pollution, and the safety matter [1-2]. Combustion of fossil fuels to generate electricity produces atmospheric CO_2 emissions. In 2005, total CO_2

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emissions were 26.6 billion tons. More than 41% of it was produced from fossil fuels consumed in the world. It will increase to 46% by 2030. CO_2 gas in large amount released to the atmosphere as the primary cause of global warming [3-5]. Therefore, the application of natural ventilation is very important in reducing the global warming effects, and the application of natural ventilation in the building is necessary to evaluate in order to find out the effective natural ventilation system. This study aims to identify the characteristics of natural ventilation in the Sultanate of Ternate Mosque (STM).

2. Research Methodology

This research is qualitative research that emphasizes on the identification of the Natural ventilation system, through: (1) Field study: direct of observation and measurement in the field to obtain primary data; dimension, type, and orientation of ventilation. (2) Literature review: to complement secondary data information about the performance of clerestory ventilation and cross ventilation system. (3) Interviews: to obtain information relating to primary and secondary data to supplement data obtained through field studies and literature studies.

3. Natural Ventilation System

Natural ventilation is an energy efficient alternative for reducing energy use in buildings, achieving thermal comfort, and maintaining a healthy indoor environment [6-8]. Typically, the energy cost of a naturally ventilated building is 40% less than that of an air-conditioned building [9]. Natural ventilation has become a new trend in building design in the architectural community [10, 11]. Natural ventilation is an important and efficient passive technique to reduce building cooling energy need and improve indoor air quality [12].

a. STM Building in front of.

b. Main room of STM Building.

c. Main Entrance

d. Terrace

Figure 1. STM Building Model.

There are a number of different natural ventilation air flow paths in buildings, the three main ones being: cross ventilation, single-sided ventilation, and passive stack ventilation. In cross ventilation system, the inlet and outlet are generally located in a different side, and for Single-side ventilation, the inlet and outlet are generally at the same side. Stack ventilation (outward air flow) is generally assumed to be driven by temperature differences between the hot air in the occupied space and the cooler external air. For STM Building uses the cross ventilation system with combination wall ventilation and roof ventilation (see figure 1).

Sultan Ternate Mosque is the oldest mosque in Ternate, North Maluku. It was rebuilt around 1807-1821 periods because of burned. The mosque is also known as the *Sigi Lamo* with the main room area (prayer room) of about 486 m^2. At the beginning construction of this mosque, the roof material used sago palm leaves, and it was replaced with zinc material on 1983 [13]. Model of STM building is unique with 7 levels roof and without ceiling (see figure 1). This model can improve the performance of natural ventilation.

4. Openings Type of STM Building

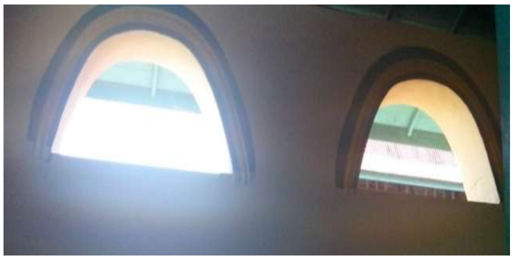
A naturally ventilated structure often includes an articulated plan and large window and door openings, while an artificially conditioned building is sometimes best served by a compact plan with sealed windows. The specific approach and design of natural ventilation systems will vary based on building type and local climate. However, the amount of ventilation depends critically on the careful design of internal spaces, and the size and placement of openings in the building [14].

a. Entrance (P1).

b. Side door (P2).

c. Roof ventilation (V1).

e. Wall Jalousie (J1).



d. Wall Ventilation (V2).

Figure 2. Openings type of STM Building.

Figure 2 portrays that the opening types of STM Building are consist of 5 models: double doors (P1), double doors-jalousie (P2), window/wall ventilation (V2), and jalousie in wall and roof (J1 & P1). According to Moore [15] that Jalousie (J1 & V1) can circulate air of about 15%, and 90% in V2 model. For double swing door of P1 and P2 models can circulate air of about 90% at the open condition, and P2 model (closed condition) can circulate air of about 15 % through jalousie on the door. It indicates that the performance of natural ventilation in the STM Building is optimal by a combination of clerestory ventilation and cross ventilation systems especially during prayer time (open doors condition).

5. Openings Orientation of STM Building

Cross ventilation relies on wind for cooling. When the wind blows on a building, a pressure difference is created between the windward (wind-facing) and leeward walls. Openings placed on opposite sides of a building will allow the cooler external air to enter the building while warmer internal air is sucked out from the leeward side openings. The degree of passive cooling is determined by the size and placement of the building and ventilation openings, as well as the regularity of wind [16]**.** Figure 3 portrays that the opening position and orientation of STM building, where the inlet is located in the east wall at the position of the wind in the east wall of the building so it will affect the increased flow of air inside the room past the area of prayer to the inlet on the west wall of the building. These conditions can influence the indoor thermal comfort at the prayer room.

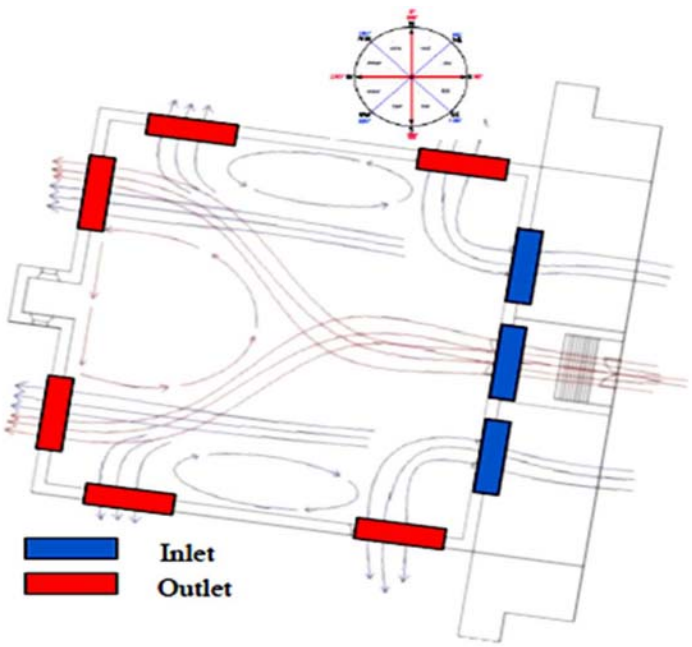
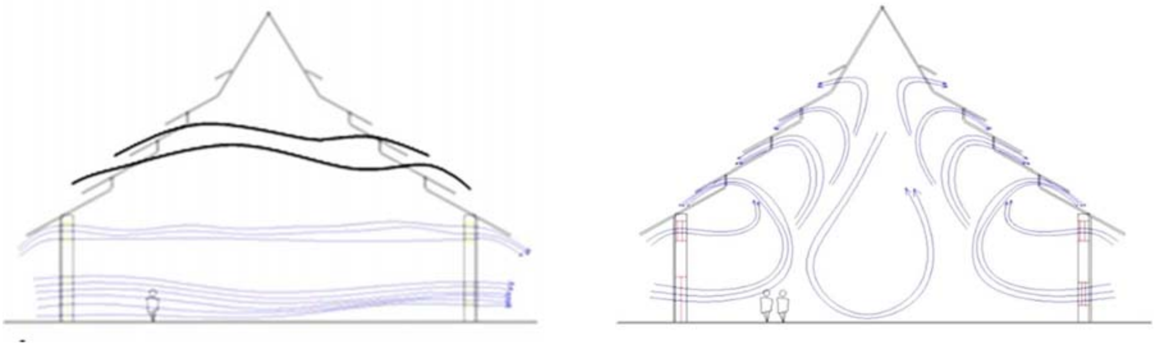


Figure 3. Openings position and orientation in the STM Building.

The ideal position of an inlet is about the height of human activity, whereas outlet position should be higher than the inlet position so that the hot air can be removed easily without mixed with fresh air coming through the inlet. The height of human activity in the room is around of 60-80 cm for prayer activity and around of 100-160 cm for standing activity.

Figure 4 shows the cross ventilation performance in STM Building, where the air flows from the door in east side (inlet) to window and jalousie in west side (outlet) flows through the height of human activity during prayer (see figure 4a). In addition, the roof ventilation that is located on four sides of the building can facilitate circulation of air inside the room through a system of cross ventilation. Hot air is at top of the room easily flow out through roof ventilation (see figure 4b). Therefore, the indoor thermal comfort can be archived especially during daylight time. According to Aynsley [17] that indoor thermal comfort can be achieved from natural ventilation more often during daylight hours of 103 out of 124 occasions; when wind speeds are higher and relative humidity is lower than during night time, and 79 out of 124 occasions in night time; when relative humidity rises and calms in wind are more frequent.



a. Horizontal circulation b. Vertical circulation

Figure 4. Cross ventilation system in STM Building.

Opening types in STM Building are door, window, wall ventilation (jalousie) and roof ventilation. They can improve the wind circulation in indoor so that the hot air in the room can flow to the outdoor optimally, and then thermal comfort in indoor can be achieved. According to Karava [18] that the internal airflow pattern has a significant impact on induced airflow rate and internal pressure distribution; this effect is more pronounced for configurations with large wall porosities (higher than 10%).

Area size of main room of STM Building is around 484 m^2 so that the minimum of openings is required of about 96,8 m^2 (openings standard is 20% of the total room size [19-20]). Figure 5 and table 1 show that the openings dimension of STM Building is around 87,52 m^2 in the wall (entrance and window/jalousie types) and 22,72 m^2 in the roof of building (roof ventilation type), with the total size of opening is about 110,2 m^2 or 22,78 % of the total room size. It indicates that the openings of the STM Building are more than the openings standard. Therefore, it can optimize cross ventilation in the building. Moreover, the size of the inlet is around 56,13 m^2 and outlet of about 54,13 m^2. It indicates that the inlet size higher than outlet size. This condition can increase air flow in the room so that the indoor thermal comfort can be achieved. Natural ventilation is useful for improving thermal comfort in hot climates [21-24]. According to Aldawoud [25], the cross-ventilation may offer significant potential to improve the indoor thermal environment and comfort conditions to acceptable levels, indoor temperature reductions of 4–8°C are possible, air flow rate and the indoor temperature are directly proportional with the size of inlets and outlets. Higher flow rates occur with large inlets and outlets that have a proper orientation as regards prevailing wind.

Table 1. Ventilation size of STM Building.

Type Code	Ventilation Type	Ventilation total	Ventilation size (m^2)
P1	Main Entrance	1	5,00
P2	Side entrance	2	8,00
J1	Window/Jalousie	6	26,52
V1	Roof ventilation	16	48,00
V2	Wall ventilation	16	22,72
		Total	110,24

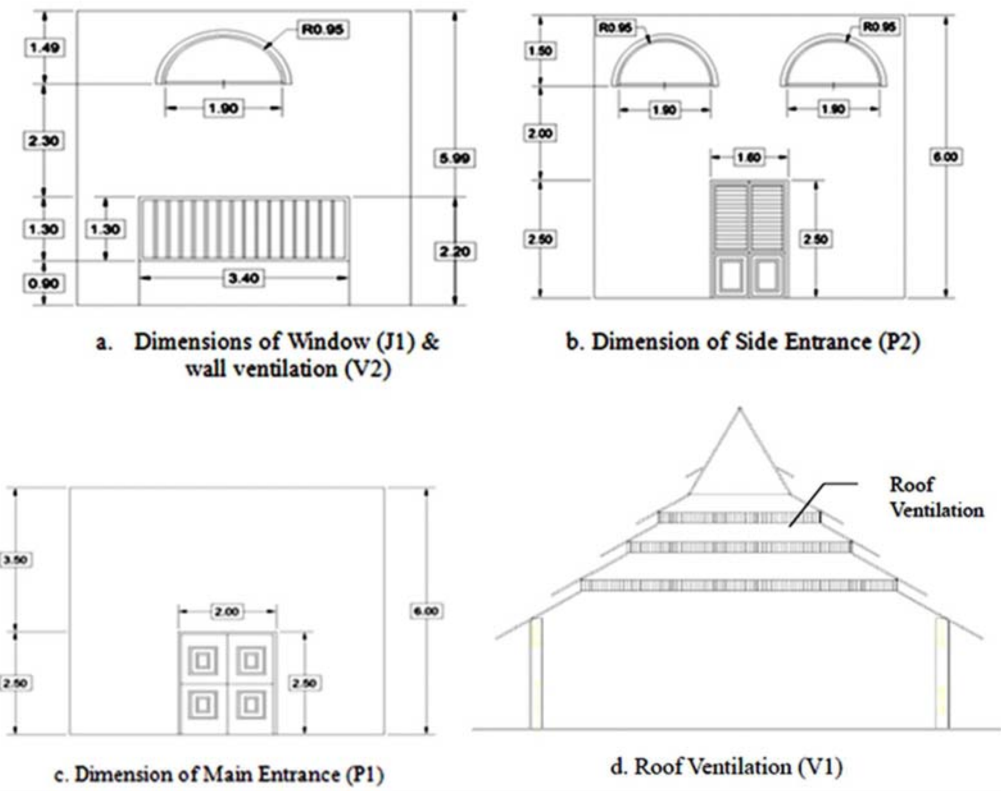


Figure 5. Openings dimension of STM Building.

6. Conclusions

Based on the evaluation, it can be concluded that:

i. Natural ventilation system in STM Building uses clerestory ventilation and cross ventilation systems, so that, the indoor thermal conditions can reach a comfortable level.
ii. Ventilation types are semicircular and vertical jalousie on the walls, and roof ventilation of 4-levels.
iii. Total area of openings is 110.24 m^2 or around 22,78 % of the total room size, with the ventilation ratio is about 1.04 (inlet): 1.00 (outlet). It indicates that the natural ventilation in the STM Building is optimal to improve indoor thermal comfort, especially during prayer time.

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